# EFFECT OF ADMIXTURE ON THE PROPERTIES OF CONCRETE (A CASE STUDY OF POTASSIUM CHLORIDE AND CAUSTIC SODA)

BY

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOY FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF POST GRADUATE DIPLOMA(PGD) IN CIVIL ENGINEERING

FEBRUARY, 2011.

# DECLARATION

I, Inetianbor Oseghale Clement, PGD/CE/2008/032 hereby declare that I carried out this project work under the supervision of Engr. Dr. J.I. Aguwa. The project has not been submitted in any form and anywhere for the award of any degree. All sources of information are specially acknowledged and referenced.

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**INETIANBOR O. CLEMENT** **Date**

## CERTIFICATION

This is to certify that this project work was carried out by INETIANBOR OSEGHALE CLEMENT under the supervision of Engr. Dr. Aguwa and submitted to Civil Engineering Department in partial fulfillment for the award of a Post Graduate Diploma (PGD) in Civil Engineering. All sources of information have been duely acknowledge and refe

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## DEDICATION

This project is specially dedicated to the ALMIGHTY GOD who is my creator and father. I also dedicate this project to my loving wife and the entire members of my family, MR. & MRS. JACOB E. A. INETIANBOR who have wholly (with the aid of God's patience, tolerance, providence and goodwill) made it possible for me to attain this height in my academic pursuit.

## ACKNOWLEDGEMENT

I sincerely express my honour and thanks to the most HIGH GOD for the strength, zeal and sense of direction granted me to achieve this goal, and the grace to have acquired much knowledge and experience.

I acknowledge with great thanks to the fatherly, moral and effective supervision of my project supervisor, ENGR. DR. J. I. AGUWA and all members and staff of the Department of Civil Engineering, Federal University of Technology, Minna whom I directly or indirectly trained during my course of tolerance, kindness, guidance, love and co-operation.

My thanks also goes to all my friends, colleagues and professional partners for their unreserved advice, support and prayers.

## ABSTRACT

This project examined the effects of admixture on concrete. Three different mixes of concrete cubes of 1:2:4 mix ratio were produced by manual mixing with the application of two different admixtures(Potassium Chloride and Caustic soda) on two separate mixes respectively and the third mix without admixture.

The cubes so produced were subjected to curing for 7,14,21 and 28 days respectively and crushing tests were carried out at ages stated. The results obtained varies due to the effects of admixture on the concrete. It was found that the Potassium chloride admixture retards both the initial and final set of the concrete as a result of its base chemical and produced concrete with the highest strength which increased progressively as the age increased. The Caustic soda admixture accelerates the setting time of the concrete and reduced the water content in the concrete mix during the chemical hydration reaction, thereby yielding a low workability, and produced concrete with the lowest strength.

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## CHAPTER ONE

## 1.0 INTRODUCTION

Economical, durable construction with concrete requires a thorough knowledge of its properties and behavior in service of approved design procedures and of recommended field practices. Not only is such knowledge necessary to avoid disappointing results, especially when concrete is produced and cast on the building site, but also to obtain maximum benefits from its unique properties.

This project therefore looks in more detail the uses and effects of admixture on concrete production.

Admixture is a material other than hydraulic cement, aggregate, or water, used as an ingredient of concrete added during its mixing to modify its properties. Concrete is a mixture of Portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water with or without admixture.

The effects of using admixture on concrete production is either to enhance its strength and durability when exposed to sunlight, freezing, salt or any other condition. Admixture also retard concrete strength and durability under similar conditions of exposure.

### 1.1 BACKGROUND INFORMATION

Cementitious materials include the many products that are mixed with either water or some other liquid or both to form a cementing paste that may be formed or molded while plastic but will set into a rigid shape. When sand is added to the paste, mortar is formed. A combination of coarse and fine aggregate(sand) added to the paste forms concrete.

Concrete is one of the most paramount construction materials in the world. It's a mixture of portland cement, water, fine and coarse aggregates, and occasionally admixtures proportioned to form a plastic mass capable of being cast, placed or molded into forms that will harden to a solid mass. The use of concrete in construction is an aged - long practice and its desirable properties are that it should be workable, placeable and nonsegregating and set in the desired time.

## 1.2 PROBLEM STATEMENT

The time duration of projects execution and handing over is a challenging factor in construction industry. Over - time most project managers are not able to deliver projects as at when due because of the excessive time spent in the construction of some structural elements like concrete and others. Concrete production can be accelerated by the use of admixture which speed - up its setting and hardening time and also improves its properties.
This project sets out to investigate the effects of the selected admixtures on the properties of concrete in global construction industry.

## 1.3 AGGREGATES

Aggregates can be divided into two parts namely fine and coarse aggregates. Aggregates are generally cheaper than cement and impart greater volume stability and durability to concrete. The aggregate is used primarily for the purpose of providing bulk to the concrete. To increase the density of the resulting mix the aggregate is frequently used in two or more sizes. The most important function of the fine aggregate is to assist in producing workability and uniformity in mixture.

### 1.3.1 CLASSIFICATION OF AGGREGATES

1. Classification according to size:
   a. Fine aggregate: These are aggregates which passes through a 4.75mm (5mm) sieve. Sand is generally considered as a fine aggregate and also considered to have a lower size limit of about 0.07mm.

   b. Coarse aggregate: These are aggregates most of which are retained on the 5mm sieve. The coarse aggregate may be of the following types.
      i. Crushed gravel or stone obtained by the crushing of gravel or hard stone.
      ii. Uncrushed gravel or stone resulting from natural disintegration of rock or
      iii. Partially crushed gravel or stone obtained as a product of the blending of the above two types.

   c. All-in-aggregates:- Aggregates comprising different fractions of fine and coarse aggregates are known as all-in-aggregates.

   d. Single – size aggregates:- Aggregate consisting of particles falling essentially within a narrow limit of size fractions are called single size aggregates.

2. Classification of aggregates according to origin:
   a. Natural aggregates:- These are aggregates that are generally obtained from natural deposits of sand and gravel or from quarries by cutting rocks.

b. Artificial aggregates:- These are aggregates that are made by human being rather than occurring naturally. Examples include clean broken bricks, air cooled fresh blast – furnance – slag, sintered shale, sintered – pulverished – fuel ash e.t.c.

3. Classification of aggregates according to shape:

i. Rounded aggregates: This aggregates give minimum ratio of surface area to volume. It has poor bonding making it unsuitable for high strength concrete and pavement.

ii. Irregular aggregates:- These are aggregates having irregular shape i.e having partly rounded particles. Their interlocking between particles though better than that obtained with rounded aggregates is inadequate for high strength concrete.

iii. Angular aggregates:- These are aggregates with sharp angular and rough particles and are of generally crushed rock. The aggregate requires more cement paste to make workable concrete of high strength than that required by rounded particle. Angular aggregate is suitable for high strength concrete and pavements subjected to tension.

iv. Flaky and Elongated aggregates:- These are aggregates having their length considerably larger than the width and the width considerably larger than the thickness. Their demerits is that they tend to orientate in one plane with water and air voids forming beneath.

4. Classification based on Unit weight:

i. Normal weight aggregates:- These are commonly used aggregates which include sands and gravels, crushed rocks such as granite, basalt, quarts, sandstone and limestone e.t.c. which have specific gravities between 2.5 and 2.7 and produces concrete with a density in the range of $2300kg/m^3 – 2500kg/m^3$.

ii. Heavy weight aggregates:- These types of aggregates provide an effective and economical use of concrete for radiation shielding by giving the necessary protection against x-rays, gamma rays and neutron and for weight floating of submerged pipelines. Examples are iron shots, lead shots, magnetite. The specific gravity of heavy weight aggregates ranges between 2.8 and 2.9 while the density of heavy weight concrete ranges between $4000kg/m^3$ to $8500kg/m^3$.

iii. Light weight aggregates:- The density of light weight aggregate ranges between $350kg/m^3$ to $850kg/m^3$ (for coarse aggregate) and $750kg/m^3$ to $1100kg/m^3$ (for fine aggregate) while the specific gravity is less than 2.6. Examples include foamed slag, expanded clay, expanded slag etc. The aggregates are used for variety of concrete products ranging from insulating screeds to reinforced or prestressed concrete although their greatest use has been in the manufacture of precast concrete blocks.

### 1.3.2 PROPERTIES OF AGGREGATES

Many properties of aggregates depends on the properties of the parent rock sample, classification and shape and texture classification. There are other properties of aggregates which are absent in the parent rock which can be grouped into mechanical, physical and thermal properties. All these properties may have considerable influence on the quality of fresh and hardened concrete.

a. <u>Mechanical Properties of Aggregates</u>: The following properties stated below give an indication of the quality of the aggregate.

1. Strength:- This is a measure of the ability of an aggregate particle to withstand pulling or crushing force. Clearly, the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained there-in, although it is not easy to determine the crushing strength of the aggregate itself. The required information about the aggregate particles has to be obtained from indirect tests. The aggregate crushing value (ACV) test as presented by BS 812: Part 110: 1990 is a useful guide when dealing with aggregate of unknown performance.

2. Toughness:- This is defined as the resistance of aggregate to failure by impact, and it is usual to determine the aggregate impact value of bulk aggregate. Full details of the prescribed tests are given in BS 812: Part 112: 1990. The impact is provided by a standard hammer falling 15 times under its own weight upon the aggregate in a cylindrical container. This results in fragmentation similar to that produced by the plunger in the crushing value test. BS 882: 1992 prescribes the following maximum values of the average duplicate samples.

   i. 25 percent when the aggregate is to be used in heavy - duty concrete floor finishes.
   ii. 30 percent when the aggregate is to be used in concrete pavement, wearing surfaces and
   iii. 45 percent when to be used in other concrete.

3. Hardness:- Hardness or resistance to wear is an important property of concrete used in roads and in floor surfaces subjected to heavy traffic. The

aggregate abrasion value of the bulk aggregate is assessed using BS 112: Part 113: 1990.

The aggregate abrasion value is defined as percentage loss in mass on abrasion, so that a high value denote a low resistance to abrasion.

4. Bond:- Both the shape and surface texture of aggregate influence considerably the strength of concrete, especially so far high strength concrete, flexural strength is more affected than compressive strength. A rougher texture results in a greater adhesion or bond between the particles and the cement matrix. Likewise the large surface area of a more angular aggregate provides a greater bond. Generally the texture characteristics which permit no penetration of the surface of the particles by the paste are not conducive to good bond, and hence softer, porous and mineralogical homogeneous result in a better bond.

The determination of the quality of bond is rather difficult and no accepted test exists. Generally when bond is good, a crushed concrete specimen should contain some aggregate particles broken right through, in addition to the more numerous ones separated from the paste matrix. However, an excess of fractured particles suggests that the aggregate is too weak.

b. Physical properties of Aggregates: Several common physical properties of aggregates of the kind familiar from the study of elementary physics are relevant to the behavior of aggregate in concrete and to the properties of concrete made with the given aggregate. Below are the physical properties of the aggregate which are discussed in chapter 3.

i. Specific gravity

ii. Bulk density

iii. Void ratio
iv. Porosity
v. Absorption
vi. Moisture content

## 1.4 CEMENT

Cement is a grey powder that become hard and strong when it is mixed with water and then left to dry. Cement are used for various purposes such as binding sand and gravel together with Portland cement to form concrete, for uniting the surfaces of various materials or for coating surfaces to protect them from chemical attack.

### 1.4.1 TYPES OF CEMENT

The various types of cement include the following:

1. Ordinary Portland cement (OPC) – Type 1 and II
2. Rapid hardening Portland Cement
3. Extra – rapid hardening Portland cement
4. Sulphate resisting cement
5. Air entraining cement
6. Ultral – rapid cement
7. White and coloured cement
8. Hydropholic cement
9. Slag cement
10. Pozzolaric cement
11. High aluminate cement
12. Low heat Portland cement

### 1.4.2 CHEMICAL COMPOSITION OF CEMENT

As a result of the chemical changes that takes place during the process of manufacture of cement, several compounds are formed in the resulting cement although only four are generally considered to be important. There are however minor compounds.

**Table 1: Important compounds of cement (Major compounds)**

| Name of Compound | Chemical Composition | Usual abbreviation |
|---|---|---|
| Tricalcium Silicate | $3Ca0.Si0_2$ | $C_3S$ |
| Dicalcium Silicate | $2Ca0.Si0_2$ | $C_2S$ |
| Tricalcium aluminate | $3Ca0.Al_20_3$ | $C_3A$ |
| Tetracalcium aluminoferrite | $4Ca0.Al_20_3Fe_20_3$ | $C_4AF$ |

$C_3S$ – This compound is responsible for the development of early strength particularly during the first 14 days. The rate of hydration at an early stage is rapid.

$C_2S$ –This compound hydrates slowly at an early stage and is mainly responsible for the development in strength after about 7 days and may be active for a considerable period of time. Cement richer in $C_2S$ results in a greater resistance to chemical attack and has a smaller dry shrinkage than do other Portland cement.

$C_3A$ – This compound produces little increase in strength after about 24 hours. Of the four major compounds, tricalcium aluminate ($C_3A$) is the least stable and cement containing more than 10% of this compound produces concrete which are particularly susceptible to sulphate attack.

$C_4AF$ – This compound hydrates rapidly but its individual contribution to the overall strength of cement is insignificant. However, it is more stable than $C_3A$.

Minor compounds of cement: In addition to the main compounds listed above, there exist minor compounds such as magnesia ($Mg0$), Titanium dioxide ($Ti0_2$) Potassium oxide ($K_20$), Sodium oxide ($Na_20$) etc. they usually amount to not more than a few percentage of the mass of cement.

Two of the minor compounds are of interest, the oxide of sodium and potassium, $Na_20$ and $K_20$ known as the alkalis (although other alkalis also exist in cement). They have been found to react with some aggregates, the products of the alkali – aggregate reaction causing disintegration of the concrete and have also been observed to affect the rate of gain of strength of cement. It should be noted that the term minor compounds refers primarily to their quantities and not necessarily to their importance.

### 1.4.3 BOGUE'S EQUATION

These equations are used to determine the percentages of main compounds in cement. The equations are given below:

From R.H. Bogue;

$C_3S = 4.07(Ca0 - \text{free oxide of } CaO) - 7.60\,(Si0_2) - 6.72\,(Al_20_3) - 1.38(Fe0_3) - 2.85\,(S0_3)$

$C_2S = 2.87(Si0_2) - 0.754\,(3Ca0.Si0_2)$

$C_3A = 2.65\,(Al_20_3) - 1.69\,(Fe_20_3)$

$C_4AF = 3.04\,(Fe_20_3)$

Therefore,

$C_3S = 4.07(64.73 - 1.60) - 7.60(21.20) - 6.72(5.22) - 1.38(3.08) - 2.85(2.01) = 50.76\%$

$C_2S = 2.87(21.20) - 0.754(50.76) = 22.57\%$

$C_3A = 2.65(5.22) - 1.69(3.08) = 8.62\%$

$C_4AF = 3.04(3.08) = 9.36\%$

### 1.4.4 FINENESS OF CEMENT

The fineness of cement is a measure of the size of particles of cement and is expressed in terms of specific surface of cement. It can be calculated from particle size distribution or one of the air permeability methods.

### 1.4.5 SETTING TIME OF CEMENT

Cement when mixed with water forms paste which gradually becomes less plastic and finally a hard mass is obtained. In this process of setting, a stage is reached when the paste is significantly rigid to withstand a definite amount of pressure. The time to reach this stage is termed setting time.

### 1.4.6 SOUNDNESS OF CEMENT

The soundness of cement is caused by the undesirable expansion of some of its constituents, sometimes after setting. The large change in volume accompanying expansion results in disintegration and severe cracking. The unsoundness is due to the presence of free lime and magnesia in the cement.

The unsoundness may be reduced by:

1. Limiting the magnesia (Ma0) content to less than 0.5 percent
2. Fine grinding.
3. Allowing the cement to aerate for several days
4. Thorough mixing

### 1.4.7 FUNCTIONS OF CEMENT

1. Cement is used to bind the sand and coarse aggregate together.
2. Cement help to fill the voids in between sand and coarse aggregate particles to form a compact mass.

### 1.5 WATER

Water is the most important and least expensive ingredient of concrete. A part of mixing water is utilized in the hydration of cement to form the binding matrix in which the inert aggregates are held in suspension until the matrix has hardened. The remaining water serves as a lubricant between the fine and coarse aggregates and makes concrete workable, i.e. readily placeable in forms.

Generally, cement requires about three – tenth of its weight of water for hydration. Hence the minimum water – cement ratio required is 0.30. But the concrete containing water in this proportion will be very harsh and difficult to place. Additional water is required to lubricate the mix, which makes the concrete workable. This additional water must be kept to minimum, since too much water reduces the strength of concrete. The water – cement ratio is influenced by grade of concrete, nature and type of aggregates, the workability and durability e.t.c.
If too much water is added to concrete, the excess water along with cement comes to the surface by capillary action and this cement water mixture forms a scum or thin layer of chalky material known as laitance.

This laitance prevent bond formation between the successive layers of concrete and forms a plane of weakness. Excess water may also leak through the joints of the formwork and make the concrete honey – combed. As a rule, the smaller the percentage of water, the stronger is the concrete subject to the condition that the required workability be allowed for.

### 1.5.1 QUALITY OF MIXING WATER

The water used for the mixing and curing of concrete should be free from injurious amount of deleterious materials. The unwanted situations leading to the distress of concrete, have been found to be as a result of, among others, the mixing and curing water being of inappropriate quality. Portable water is generally considered satisfactory for mixing concrete.

### 1.5.2 EFFECT OF IMPURITIES IN WATER ON PROPERTIES OF CONCRETE

1. The strength and durability of concrete is reduced due to the presence of impurities in mixing water.

2. Water containing large quantities of chlorides tends to cause persistent dampness, surface efflorescence and increases the corrosion of the reinforcing steel.

3. The presence of salts of manganese, tin, zinc, copper and lead in water causes reduction in the strength of concrete. The zinc chloride retard the setting of concrete to such an extent that no strength tests are possible at 2 and 3 days.

4. Some salts like sodium iodate, sodium phosphate, sodium arsenate and sodium borate reduces the initial strength of concrete to a very low degree.

5. The carbonate of sodium and potassium may cause extremely rapid setting and in large concentrations, reduces the concrete strength.

6. Algae present in the mixing water combine with cement and reduces the bond between aggregates and cement paste. The water containing algae has the

effect of entraining large quantities of air in concrete and thus lowering the strength of concrete.

## 1.6 ADMIXTURES

Admixtures are anything other than Portland cement, water and aggregates that are added to a concrete mix to modify its properties. Included in this definition are chemical admixtures, mineral admixtures such as fly ash and silica fume, corrosion inhibitors, colors, fibres and miscellaneous (pumping aids, damp proofing, gas - forming, permeability – reducing agents).

### 1.6.1 CHEMICAL AND MINERAL ADMIXTURES

Chemical admixtures used in concrete generally serve as water reducers, accelerators, set retarders, or a combination. Standard specification for chemical admixtures for concrete contains the following classification:

**Table 2: Classification of Chemical Admixtures**

| Type | Property |
|---|---|
| A | Water reducer |
| B | Set retarder |
| C | Set accelerator |
| D | Water reducer & set retarder |
| E | Water reducer and set accelerator |
| F | High – range water reducer |
| G | High – range water reducer & set retarder |

### 1.6.2 WATER REDUCING ADMIXTURES

These decrease water requirements for a concrete mix by chemically reacting with early hydration products to form a monomolecular layer of admixture at the cement – water interface. This layer isolates individual particles of cement and reduces the energy required to cause the mix to flow. Thus, the mix is 'lubricated' and exposes more cement particles for hydration.

The Type A admixture above allows the amount of mixing water to be reduced while maintaining the same mix slump. Or at a constant water - cement ratio, this admixture allows the cement content to be decreased without loss of strength. If the amount of water is not reduced, slump of the mix will be increased and also strength will be increased because more of the cement surface area will be exposed for hydration. Similar effects occur for Type D & E admixtures. Typically, a reduction in mixing water of 5 to 10% can be expected.

Type F and G admixtures are used where there is a need for high – workability concrete. A concrete without an admixture typically has a slump of 2 to 3 in. After the admixtures is added, the slump may be in the range of 8 to 10 in without segregation of mix components. These admixtures are especially useful for mixes with low water – cement ratio. Their 12 to 30% reduction in water allows a corresponding reduction in cementitious material.

The water – reducing admixtures are commonly manufactured from liguosulfonic acids and their salts, hydroxylated carboxylic acids and their salts, or polymers of derivatives of melamines or naphthalene or sulfonated hydrocarbons. The combination of admixtures used in a concrete mix should be carefully evaluated and tested to ensure that the desired properties are achieved. For example, depending on the dosage of admixture and chemistry of the cement, it is possible that a retarding admixture will accelerate the set.

Superplasticizers: These are high – range water – reducing admixtures that meet the requirements of Type F or G. They are often used to achieve high – strength concrete by use of a low water – cement ratio with good workability and low segregation. They also may be used to produce concrete of specified strengths with less cement at constant water – cement ratio. And they may be used to produce self – compacting, self – leveling flowing concretes, for such applications as long – distance pumping of concrete from mixer to formwork or placing concrete in forms congested with reinforcing steel.

Superplasticizers may be classified as sulfonated melamine – formaldehyde condensates, sulfonated naphthaline – formaldehyde condensates, modified liguosulfonates, or synthetic polymers.

### 1.6.3 AIR – ENTRAINING ADMIXTURES

These create numerous microscopic air spaces within concrete to protect it from degradation due to repeated freezing and thawing or exposure to aggressive chemicals. For concrete exposed to repeated cycles of freezing and thawing, the air gaps provide room for expansion of external and internal water, which otherwise would damage the concrete.

Since air – entrained concrete bleeds to a lesser extent than non – air entrained, there are fewer capillaries extending from the concrete matrix to the surface. Therefore, there are fewer avenues available for ingress of aggressive chemicals into the concrete.

### 1.6.4 SET – ACCELERATING ADMIXTURES

These are used to decrease the time from the start of addition of water to cement to initial set and to increase the rate of strength gain of concrete. The most commonly used set – accelerating admixture is calcium chloride. Its use, however, is controversial in cases where reinforcing or prestressing steel is present. The reason is that there is a possibility that the accelerator will introduce free chloride ions into the concrete, thus contributing to corrosion of the steel. An alternative is use of one of many admixtures not containing chloride that are available.

### 1.6.5 RETARDING ADMIXTURES

To some extent, all normal water – reducing admixtures retard the initial set of concrete. A Type B or D admixture will allow transport of concrete for a longer time before initial set occurs. Final set also is delayed. Hence, precautions should be taken if retarded concrete is to be used in walls.

Depending on the dosage and type of base chemical in the admixture, initial set can be retarded for several hours to several days. A beneficial side effect of retardation of initial and final sets is an increase in the compressive strength of the concrete. A commonly used Type D admixture provides higher 7 – and 28 – days strength than a Type A when used in the same mix design.

### 1.6.6 MINERAL ADMIXTURES

Fly ashes, pozzolane and microsilicates are included in the mineral admixture classification. Natural cement is sometimes used as an admixture.

### 1.6.7 CORROSION INHIBITORS

Reinforcing steel in concrete usually is protected against corrosion by the high alkalinity of the concrete, which creates a passivating layer at the steel surface. This layer is composed of ferric oxide, a stable compound. Within and at the surface of the ferric oxide, however, are ferrous – oxide compounds, which are more reactive. When the ferrous – oxide compounds come into contact with aggressive substances, such as chloride ions, they react with oxygen to form solid, iron – oxide corrosion products. These produce a fourfold increase in volume and create an expansion force greater than the concrete tensile strength. The result is deterioration of the concrete.

For corrosion to occur, chloride in the range of 1.0 to 1.5 lb/yd$^3$ must be present. If there is a possibility that chlorides may be introduced from outside the concrete matrix, for example, by deicing salts, that concrete can be protected by lowering the water – cement ratio, or increasing the amount of cover over the reinforcing steel, or entraining air in the concrete, or adding a calcium – nitrate admixture or adding an internal – barrier admixture, or cathodic protection, or a combination of these methods.

To inhibit corrosion, calcium – nitrate admixture are added to the concrete at the time of batching. They do not create a physical barrier to chloride ion ingress. Rather, they modify the concrete chemistry near the steel surface.

### 1.6.8 COLORING ADMIXTURES

Colors are added to concrete for architectural reasons. They may be mineral oxides or manufactured pigments. Raw carbon black, a commonly used material for black color, greatly reduces the amount of entrained air in a mix. Therefore, if black concrete is desired for concrete requiring air – entrainment (for freez-thaw or aggressive chemical exposure), either the carbon black should be modified to entrain air or an additional air – entraining agent may be incorporated in the mix. The mix design should be tested under field conditions prior to its use in construction. Use of color requires careful control of materials, batching and water addition in order to maintain a consistent color at the jobsite.

### 1.6.9 FIBERS FOR CONCRETE MIXES

As used in concrete, fibers are discontinuous, discrete units. They may be described by their aspect ratio, the ratio of length to equivalent diameter. Fibers find their greatest use in crack control of concrete flatwork, especially slabs on grade.

The most commonly used types of fibers in concrete are synthetics, which include polypropylene, nylon, polyester, and polyethylene materials. Specialty synthetics include aramid, carbon, and acrylic fibers. Glass – fibers – reinforced concrete is made using E – glass and alkali – resistance (AR) glass fibers. Steel fibers are chopped high – tensile or stainless steel. With steel fibers, impact strength and toughness of concrete may be greatly improved and flexural and fatigue strengths enhanced.

Synthetic fibers are typically used to replace welded – wire fabric as secondary reinforcing for crack control in concrete flatwork. Aramid, carbon, and acrylic fibers have been studied for structural applications, such as wrapping concrete columns to provide additional strength. Other possible uses are for corrosion – resistance structures. Glass – fiber – reinforced concrete (GFRC) is used to construct many types of building elements, including architectural wall panels, roofing tiles and water tanks. Steel fibers can be used as a structural material and replace conventional reinforcing steel.

### 1.6.10 MISCELLANEOUS ADMIXTURES

There are many miscellaneous additives for use as pumping aids and as dampproofing, permeability – reducing, gas forming agents.

**Pumping aids** are used to decrease the viscosity of harsh or marginally pumpable mixes. Organic and synthetic polymers, fly ash, bentonite, or hydrated lime may be used for this purpose. Results depend on concrete mix, including the effects of increased water – cement ratio. If sand makes the mix marginally pumpable, fly ash is the preferred pumping additive. It generally will not increase the water demand and it will react with the calcium hydroxide in cement to provide some strength increase.

**Dampproofing admixtures** include soaps, stearates and other petroleum products. They are intended to reduce passage of water and water vapor through concrete. Caution should be exercised when using these materials in as much as they may increase water demand for the mix, thus increase the permeability of the concrete. If dense, low – permeable concrete is desired, the water – cement ratio should be kept to a maximum of 0.50 and the concrete should be well vibrated and damp cured.

**Permeability** of concrete can be decreased by the use of fly ash and silica fume as admixtures. Also, use of a high – range water – reducing admixture and a water – cement ratio less than 0.50 will greatly reduce permeability.

**Gas – forming admixtures** are used to form light weight concrete. They are also used in masonry grout where it is desirable for the grout to expand and bond to the concrete masonry unit. They are typically an aluminum powder.

## 1.7 AIM OF STUDY

The main aim of this project is to investigate the effects of potassium chloride and caustic soda admixtures on the properties of concrete.

## 1.8 OBJECTIVES

The objectives of this project are:

i. To carry out property test on fine and coarse aggregates
ii. To produce concrete cubes using the tested aggregates with the addition of the selected admixtures
iii. To cure the concrete cubes for 7, 14, 21 and 28 days respectively
iv. To carry out compression tests on the concrete cubes.

## 1.9 SCOPE OF WORK

The scope of this project include carrying out property tests on aggregate production of 150mm concrete cubes, curing for 7, 14, 21 and 28 days, carrying out compression test on the cubes and analysis of the results.

## 1.10 LIMITATION OF STUDY

This project is restricted to the use of Potassium chloride and Caustic soda on concrete production and their possible effects on the concrete properties.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

## 2.1 HISTORICAL BACKGROUND

Many ancient civilizations used forms of concrete, using dried mild, straw and other materials. Concrete may have been poured to build the great pyramids about 500 years ago. According to controversial research, which suggests that ancient Egyptians predated the Romans by thousand of years as inventors of concrete, the perfection of the technology was left to the Romans.

During the Romans Empire, Roman concrete was made from quicklime, pozzolanic and an aggregate of pumice. It was very similar to the modern Portland cement concrete. The wide spread use of concrete in many Roman structures has ensured that many survive to this present day.

The secrete of concrete was lost for 13 centuries until 1756 when the British engineer John Smeator, pioneered the use of hydraulic lime in concrete, using pebbles and bricks as aggregate. Portland cement was first used in concrete in the early 1840's.

Recently, the use of recycled materials as concrete ingredients is gaining popularity because of increasing stringiest environmental legislation. The most conspicuous of these is fly ash, a by product of coal – fired power plant. This is a significant impact by reducing the amount of quarrying and land fill space required, and as it acts as a cement replacement, reduces the amount of cement required to produce a solid concrete.

## 2.2 CONCRETE

Concrete is a mixture of cement, water, coarse and fine aggregates, and admixtures proportioned to form a plastic mass capable of being cast, placed, or mould into forms that will harden to a solid mass. The desirable properties of plastic concrete are that it be workable, placeable and nonsegregating and that it set in the desired time. The hardened concrete should provide the desired properties viz:

1. Strength(compressive and flexural).
2. Durability(lack of cracks, resistance to freezing and thawing and to chemical attacks, abrasion resistance and air content).
3. Appearance(color, lack of surface imperfections).

Each of these properties affects the final cost of the mix design and the cost of the in – place concrete. These properties are available from normal – weight, light – weight and heavy – weight concretes.(David J. Akers).

The study of concrete mix and its properties is so elaborate that no one researcher can cover all the necessary areas that need attention. So many authors have worked on different topics as part study on concrete mix. Some of them are mentioned below:

1. NEVILLE in 1981 studied and observed that the strength of concrete is commonly considered as its most valuable property. Although in many practical cases, other characteristics such as durability and impermeability, may in – fact be more important. Nevertheless, strength usually gives an overall picture of the quality of the concrete because strength is directly related to the structure of the hardened cement paste.

2. PRICE in 1951 revealed that the strength and other properties of concrete generally depend mostly on the material composition and the manufacturing methods of the concrete. Thus, to study and understand the effects of admixtures on the properties of concrete, a deep knowledge of the characteristic qualities of admixtures and properties of concrete is necessary in the design, construction and prediction of the performance of a large variety of concrete structures.

3. The flexural strength of concrete is determined by subjecting a plain concrete beam to flexural test under transverse loads. The theoretical maximum tensile stress reached in the bottom fibre of a standard test beam is refered to as the modulus of rupture. The magnitude of modulus of rupture depends on the dimensions of the beam and the type of loading. According to the data reported by PRICE, the ratio of modulus of rupture to compressive strength has been found to decrease with increasing compressive strength of concrete.

4. DUFF ABRAMS in 1919 studied the relationship between the strength of concrete at a given age and the water/cement ratio. He found out that the most important variables affecting the strength of concrete at a given age are the water/cement ratio and the degree of compaction. He also showed that when concrete is fully compacted, its compressive strength is inversely proportional to the water/cement ratio. In a series of tests started in 1910, WITHEY showed that compressive strength increases with age up to 50years and that logarithmic equation may be used to express the relationship.

5. FERET in 1896 discovered that the presence of air voids in concrete mix causes a reduction in the compressive strength and hence, adequate

workability for proper compaction during placing is very important. Following his study, the use of concrete in large scale works was made possible by the development of power driven mixers and aided by the discovery of vibration machines for compaction of concrete.

The America Concrete Institute Standard ACI:613 – 54, recommends an average total air content varying from 3 to 8 percent depending upon the desired workability expressed in terms of slump and also the maximum size of aggregate used in the mix. Based on the work of AKROYD, an air – entrained mix is also less liable to seggregate during mixing, transporting, placing and compacting. Bleeding is considerably reduced resulting in an improved frost resistance of the top layer of a slab.

6. WADDELL in 1974 observed that the resistance of concrete to fire is usually considered to be dependent on the materials from which it is made, its conditions, the shape and size of the structural element exposed to the fire. Thus, the thermal properties of hardened concrete that are of importance to the engineer are thermal conductivity, specific heat capacity, thermal diffusivity, coefficient of thermal expansion and adiabatic temperature rise.
7. NEVILLE stated that during curing of concrete, temperature also controls the rate of progress of the reactions of hydration and consequently affects the development of strength of concrete. He equally stated that strength of concrete depends on both age and temperature. It was discovered that the strength – maturity relation depends on the properties of the cement and on the general quality of the concrete and is valid only within a range of temperatures. This was confirmed by KLIEGER who tested ordinary Portland cement concrete with a water/cement ratio of 0.43 and an air content of 4.5 percent at $23^0C(73^0F)$ from the age of 28 – days onwards.

8. Some people worked on the relation between cube and cylinder strength of concrete. According to the data of EVANS, the ratio of cylinder to cube strength depends primarily on the level of strength and is found to be higher for high strength concrete. According to the British Standard, BS 1881 – 1952 and Indian Standard Is:456 – 1964 – 66, the cylinder strength may be taken as equal to 75 and 80 percent of the cube strength respectively.

TAYLOR recommended that the ratio of cylinder to cube strength approaches almost unity for very high strength concrete having a 28 day strength of 700kg/cm$^2$

# CHAPTER THREE

## 3.0 MATERIALS AND METHOD

## 3.1 METHOD

This involves the procedures in which the various tests on workshop/ laboratory investigations were carried out. In carrying out the various tests, different admixture were used with the same concrete mix ratio of 1:2:4.

## 3.2 MATERIALS USED

The materials used includes: Coarse aggregate(from Paiko Querry), fine aggregate(from Paiko river sand), cement(from Paiko cement depot), admixtures(from Abuja market), water(from the University water board), weighing balance, drying oven, tray, dry soft absorbent cloth, cylindrical bottle, cylindrical metal mould, sieve shake, scoop, head pan, slump cone, compacting factor apparatus (two cone shaped hopper, one above the other), shovel, trowel, tamping rod, wooden mould and electrical weighing balance, all from the School of Engineering Workshop.

## 3.3 LABORATORY TESTS

### 3.3.1 SPECIFIC GRAVITY TEST

This is the ratio of weight of sample (Coarse and fine aggregate) to weight of equal volume of water. Although, specific gravity is employed in the identification of classification of soil because the specific gravity of most soil fall within a narrow range (Charles C. Ike, 2001).

AIM: To determine the specific gravity of natural and physical aggregates.

APPARATUS: Weighing balance, dry oven, dried samples, wash bottles and cylindrical bottles.

EXPERIMENTAL PROCEDURE: The cylinder was cleaned, dried and weighted ($W_1$). Soil samples was introduced into the cylinder and weighted ($W_2$). Water was added, rubber stopper was inserted and shaken vigorously with hand until the particles were in suspension. The stopper was removed and any soil adhered to the stopper or sides of the cylinder were washed carefully into the cylinder. Water was then added to bring the bottom of the meniscus to the calibration mark. The outside and the inside of the neck above the meniscus were dried and weighted ($W_3$). The cylinder was emptied, filled with water to the lower meniscus and weighted ($W_4$).

The specific gravity was calculated thus:

$$G_S = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \qquad \text{---------------------} \; 1$$

### 3.3.2 BULK DENSITY TEST

Bulk density test was carried out on the aggregates (coarse and fine). For this test; BS 812 recognizes two methods of compaction, the loose (un – compacted) and the compacted.

APPARATUS:- Cylindrical metal mould, weighing balance, large metal tray, ruler, hand (metal) rammer and straight edge.

PROCEDURE (for coarse and fine aggregates): The cylindrical mould was weighted ($W_1$). For the un – compacted bulk density test, the aggregate was gently placed in the cylindrical mould so that it overflows. A straight edge was used to level the top and then weighted ($W_2$). The procedure was repeated 3 – times per each of coarse and fine aggregate, and the average un – compacted bulk density were determined.

To find the compacted bulk density, the cylindrical mould was filled in three layers. Each layer was rammed with 25 blows of free falling rammer. After the mould was completely filled and compacted, straight edge was used to level the top. The weight of the cylinder and compacted material was noted ($W_3$). The same procedure was repeated 3 - times per each of coarse and fine aggregate for every sample tested and the average obtained.

$$\text{Bulk density} = \frac{\text{Weight of material (Loose or compacted)}}{\text{Volume of cylinder}} \quad \text{---------- 2}$$

### 3.3.3 MOISTURE CONTENT TEST

The moisture content of soil is the amount of water contained in a known mass of the soil at a natural state express as a percentage of the soil's dry weight. It is necessary to determine the moisture content as this will help in determining the amount of water to be added to the soil during mixing to make up the desired degree of moisture content.

AIM: To determine the moisture content to fine and coarse aggregate.

APPARATUS: Can, electric weighing balance, drying oven and samples of fine and coarse aggregates.

PROCEDURES (Fine and coarse aggregate): Three empty cans were cleaned and weighed individually for three different trials, their weight taken as ($W_1$). The samples were placed in the can and their weigh was taken as ($W_2$). The can containing the samples were placed inside the oven and allowed to be dried for 24 hours before they were removed and allow cooling and weighed as ($W_3$).

$$\text{Moisture content} = \frac{W_2 - W_3}{(W_3 - W_1)} \times 100\% \quad \text{------------------ } 3$$

where:

| | | | |
|---|---|---|---|
| | $W_1$ | = | Weight of can |
| | $W_2$ | = | Weight of can + wet sample |
| | $W_3$ | = | Weight of can + oven dried sample |
| | $W_2 - W_3$ | = | Weight of water ($W_w$) |
| | $W_3 - W_1$ | = | Weight of oven dried sample ($W_d$) |

### 3.3.4 ABSORPTION TEST

Absorption of water is the weight of water absorbed by dry aggregate in reaching the saturated surface dry state and is expressed as a percentage of the weight of the dry aggregate. Water absorption is an important factor that controls workability of mix.

APPARATUS: Weighing balance, drying oven, a shallow tray, a mounted glass vessel such as a glass jar, an air tight container and two dry soft absorbent cloth.

PROCEDURE: The sample was placed in one of the dry clothes and surface dried. When it was discovered that the cloth will remove no further moisture, the sample was then transferred into a second cloth, spread out and left exposed to the atmosphere and away from the direct sunlight for about 20 minutes. The sample was turned over once during this period of exposure. The weight of the pan was taken as (W), the sample was placed in the pan and weighed as ($W_1$). The pan containing the sample was then placed in the oven at a temperature of $100^0C$ and left for 24 hours. After this time, removed, allowed to cool and weighed as ($W_2$). The same procedure was repeated for two additional trials and the average weight was calculated and recorded as shown in the next chapter. Hence,

$$\text{Water absorption (\% of dry weight)} = \frac{\text{Increase in weight}}{\text{Weight of oven dried sample}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots 4$$

$$\%W_A = \frac{(W_1 - W_2)}{(W_2 - W)} \times 100 = \frac{W_W}{W_d} \times 100$$

where:

$W$ = Weight of pan

$W_1$ = Weight of pan + saturated surface dry sample

$W_2$ = Weight of sample + oven dried sample

$W_w$ = Weight of water

**3.3.5 VOID RATIO**

Void ratio is defined as the ratio of volume of void to the volume of solids. The void ratio is used to determine the quantity of mortar needed in a given mix. Aggregate with the minimum volume of voids will require only a moderate amount of cement and will also produce a concrete with small drying shrinkage. The void ratio can be obtained from the following equation:

$$\text{Void ratio} = 1 - \frac{\text{Bulk density}}{\text{Specific gravity} \times \text{Unit weight of water}} \quad \ldots\ldots\ldots\ldots\ldots 5$$

### 3.3.6 POROSITY

Porosity is the ratio of the volume of voids to the total volume of material. This affects the properties of aggregates. Aggregates having high porosity will tend to produce less durable concrete, particularly when subjected to freezing and thawing than an aggregate with a lesser amount of porosity. Direct measurement of porosity is difficult, but in practice can be obtained from the result obtained from the bulk density test. Hence for this test, the porosity will be obtained in the bulk density given in the next chapter. However, the percentage porosity can be calculated as follows:

$$\text{Percentage porosity} = \left(1 - \frac{E}{S}\right) \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots.6$$

where,

E = Loose weight or un – compacted bulk density

S = Compacted bulk density.

### 3.3.5 SIEVE ANALYSIS

A sieve analysis consists of shaking the aggregates (coarse and fine) through a stock of wire screens with opening of known size.

AIM : To determine particle size distribution of the aggregates (coarse and fine).

APPARATUS: Set of sieves, weighing balance and sieve shaker.

PROCEDURE: The set of sieves was arranged from (20.0mm to 75.0μ including pan for coarse aggregate) and from (5.0mm to75.0μ including pan for fine aggregates). Coarse and fine aggregates, about 300g of sample was measured, the sample was oven dried for 24 hours. The sample was sieved through a set of sieves by means of mechanical sieve shaker. The mass retained on each sieve was weighed and recorded. Let the total mass of the sample be M, let $M_1$ be mass retained on sieve number one, let $M_2$ be mass retained on sieve number two and let $M_n$ be mass retained on the pan (n). then, $M = M_1 + M_2 + ...... + M_n$. The percentage retained on the sieves and pan are given by:

$$P_1 = (^{M}{}_1/_M) \times 100 \; ; \; P_2 = (^{M}{}_2/_M) \times 100; \; P_n = (^{M}{}_n/_M) \times 100 \quad ..............................7$$

The cumulative percentage of material retained on any sieve is equal to the sum of the percentage of soil retained on the sieve and that retained on all sieves coarser than that sieve. Therefore, $C_1 = P_1$; $C_2 = P_1 + P_2$; $C_{n-1} = P_1 + ...... + P_{n-1}$ and $C_n = P_1 + P_2 + P_n$.

The percentage finer or passing was obtained by subtracting the cumulative percentage retained on the sieve from 100%. Thus,
$N_1 = 100 - C_1$; $N_2 = 100 - C_2$ and $N_n = 100 - C_n$

A graph of percentage finer versus particle size was ploted (ie. Particle size distribution curve). Both uniformity coefficient and coefficient of curvature were evaluated. Thus,

$C_u = D_{60}/D_{10}$ and $C_C = (D_{30})^2/(D_{60} X D_{10})$
where;
$C_u$ = Coefficient of uniformity;
$C_C$ = Coefficient of curvature
$D_{10}$ = Particle size such that 10% of the sand is finer than this size.
$D_{30}$ = Particle size such that 30% of the sand is finer than this size.
$D_{60}$ = Particle size such that 60% of the sand is finer than this size.

The larger the numerical value of $C_u$, the more is the range of particles. Sands (fine aggregates) with a value of $C_u$ of 6 or more are well graded. Gravels or granite(coarse aggregates) with a value of $C_u$ of 4 or more are well graded. For a well graded sample, the value of the coefficient of curvature lies between 1 and 3.

### 3.3.6 CONCRETE MIX PROPORTIONING

Concrete is produced when water is added to suitable proportions of cement, fine aggregate and coarse aggregate. Concrete mix design is the process of selecting suitable ingredients of concrete and determining the relative quantities with the objective of producing as economically as possible concrete of certain minimum properties, notably: consistency, strength and durability.

The concrete mix design for the production of concrete cubes is calculated below:

Mix ratio = 1:2:4

Size of concrete cube = 0.15m x 0.15m x 0.15m

i. $$\text{Density} = \frac{\text{Mass (M)}}{\text{Volume (V)}} = M = PV$$

Volume of concrete cube $= 0.15 \times 0.15 \times 0.15$

$= 3.375 \times 10^{-3}\ m^3$

Density of concrete $= 24 \times 10^3\ Kg/m^3$

Mass of concrete, M = PV

$= 24 \times 1000 \times 3.375 \times 10^{-3}\ N/m^3$

$= 81N = \frac{81}{10} = 8.1Kg$

Water/ cement ratio $= 0.5$

ii. Mix ratio = 1:2:4 = 1+2+4 = 7

$ii_a$ % of cement = 1/7 x 100 = 14%

Then; 14/100 x 8.1Kg = 1.13Kg

$ii_b$ % of fine aggregate = 2/7 x 100 = 28.5 = 29%

Then; 29/100 x 8.1Kg = 2.35Kg

$ii_c$ % of coarse aggregate = 4/7 x 100 = 57%

Then, 57/100 x 8.1Kg = 4.63Kg

iii. $\frac{\text{Water}}{\text{Cement}} = 0.5$

Water content = 0.5 x cement content

= 0.5 x 1.13 = 0.57Kg

Therefore, overall mass of a cube of concrete

= 1.13 + 2.35 + 4.63 + 0.57

= 8.68Kg

$iv_a$ Quantitative of materials with potassiumChloride (KCl) for 20 cubes

Cement = 1.13kg x 20 = 22.6Kg

Fine aggregate = 2.35Kg x 20 = 47Kg

Coarse aggregate = 4.63kg x 20 = 92.6Kg

Water = 0.57kg x 20 = 11.4Kg

Potassium chloride (KCl) = 3% of 8.68Kg x 20

= 0.03 x 8.68Kg x 20

= 5.21Kg

$iv_b$ Quantitative of materials with caustic soda (Na0lt) for 20 cubes

Cement = 1.13Kg x 20 = 22.6Kg

Fine aggregate = 2.35Kg x 20 = 47Kg

Coarse aggregate = 4.63Kg x 20 = 92.6Kg

Water = 0.57Kg x 20 = 11.4Kg

Caustic soda (NaOH) = 3% of 8.68 x 20 = 5.21Kg

$iv_c$ Quantitative of materials with normal concrete for 20 cubes

Cement = 1.13Kg x 20 = 22.6Kg

Fine aggregate = 2.35Kg x 20 = 47Kg

Coarse aggregate = 4.63Kg x 20 = 92.6Kg

Water = 0.57Kg x 20 = 11.4Kg

v Adjustment for absorption

Overall weight of coarse aggregate for the 3 different mixes = 92.6Kg x 3 = 277.8Kg

% absorption of coarse aggregate (from test) = 0.43% = 0.0043Kg

Amount of water absorbed by coarse aggregate = 0.0043 x 277.8 = 1.19Kg

Overall amount of water calculated for the 3 – different mixes = 11.4x3 = 34.2Kg

Total amount of water needed = 34.2 +1.19

= 35.39kg

**3.3.81 MEAN AND MINIMUM STRENGTH OF CONCRETE**

The mean compressive strength required at a specified age, usually 28 days determine the normal water/ cement ratio of the mix. Structural design is based on the assumption of certain minimum strength of concrete produced, whether on the site or in the laboratory is a variable quantity. In mix design, we must aim at mean strength higher than the minimum. The minimum strength is the value to be exceeded by a predetermined portion of all test result, usually 95 or 99 percent. For example, the British code for the structural use of concrete Cp 110:

1972 uses the characteristics strength of concrete, which is defined as the strength exceeded by 95 percent of test specimen.

### 3.3.82 WATER/ CEMENT RATIO

Abram's water/ cement ratio law states that for any given condition of test, the strength of a workable concrete mix is dependent only on the water/ cement ratio. The water – cement ratio used for the purpose of this study is 0.5 for casting the cubes with mix ratio of 1:2:4.

### 3.3.83 BATCHING

This is the actual measuring out of the various materials to be used for the concrete production. It was done before the constituent materials were mixed together by weighing the materials using the weighing apparatus. The main purpose of weighing is to get the accurate proportion needed to obtain a desired mix concrete.

### 3.3.84 MIXING OF CONCRETE

Hand mixing method was used. It was carried out by placing the batched quantities of aggregates, cement and admixture on a concrete – mixing tray. Both the cement and fine aggregate were batched separately and were mixed together before mixing with the batched coarse aggregate and admixture. Thorough mixing was achieved. The dry materials were mixed together with shovel, forming the mixture from side to side in the mixing tray. When the heap had shown an even colour throughout the mix, water was added proportionally.

For each mix, the quantities of concrete materials were measured and mixed with the same water – cement ratio.

### 3.3.7 SLUMP TEST

This test is used extensively in site work all over the world. It is useful in detecting variations in the uniformity of a given nominal proportions.

APPARATUS: Tamping rod, mould (frustum of a cone), concrete mix and a scale for measurement.

PROCEDURE:- The cone was placed on a smooth surface with smaller opening at the top. A sample of the fresh concrete mix was then used to fill the cone in three layers by tamping each of the layers 25 times with the aid of a tamping steel rod rounded at the end and the top surface of the cone was levelled with the aid of a hand trowel. Immediately after filling, the cone was slowly lifted and the unsupported concrete now slump, hence the height of the test. The decrease in the height of the centre of the slump was measured and recorded. The same procedure was repeated for two other different trials by moistening the inside of the cone (mould) at the beginning of each test in order to reduce the influence on slump on the variation in the surface friction. The result of the test is given in the next chapter.

### 3.3.8 COMPACTING FACTOR TEST

Compacting factor is the degree of compaction which is measured by the density ratio. That is, the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

APPARATUS: Fresh concrete, hand – scoop, two towels, weighing balance, tamping rod (steel), two hoppers each in the shape of a frustum of a cone and one cylinder, the three being above one another having opening in their bottom.

PROCEDURE:- The upper hopper is filled with fresh concrete, this being placed gently so that at this stage no work is done on the concrete to produce compaction. The bottom door of the hopper is then released and the concrete falls into lower hopper. This was made smaller than upper one and therefore fill to overflowing, the bottom door of the lower hopper is released and the concrete fall into the cylinder. Excess concrete is then wiped off the cylinder mould and the net weight of concrete in the known volume of cylinder is determined.

$$\text{Compacting factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of concrete to fill cylinder without voids}} \quad \ldots\ldots\ldots\ldots 8$$

### 3.3.9 **CASTING OF CUBES**

The mould (150mmx150mmx150mm) internal dimensions were thoroughly cleaned and moisture (polished) to reduce friction and make easy for the removal of the cube. The mould was then filled in three layers (approximately 50mm deep for each layer), by tamping each layer with 25 strokes (blow) with the aid of a tamping steel rod of 450mm high & 3mm thick size. The tamping was done in a uniform manner over the cross – section of the mould. The surface of the mould was finished in order to obtain smooth faces. Appropriate records and observations of both the mixing time and setting time for the three different mixes were noted respectively, and the specimens were then left for 24 hours before demoulding.

### 3.3.12 COMPRESSION TEST

APPARATUS:- Concrete cube specimen, weighing balance, compression machine.

PROCEDURE:- During each of the testing days (i.e 7, 14, 21 & 28 days) 5 cubes each of potassium chloride mix, caustic soda mix and the control mix were removed and allowed to dry in air, each of the cubes was weighed and axially placed in the compression machine (central to the crushing load). Then the machine was on and the load applied to crush the cube. The same procedure was carried out for each of the cubes and the compressive strength were determined for each of the test days.

The compressive strength at any given age is given as:-

$$\frac{\text{Maximum load at failure}}{\text{Test cube cross – sectional area}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 9$$

**CALCULATION METHOD**

a. Density (p) = $\dfrac{\text{Mass of cube}}{\text{Volume of cube}}$

Volume of cube = 150mm x 150mm x 150mm

= $3{,}375{,}000mm^3$ = $0.00338m^3$

Area of cube = 150mm x 150mm

= $22500mm^2$

b. Compressive strength ($f_c$) = $\dfrac{\text{Maximum load at failure}}{\text{test cube cross – sectional area}}$

= $\dfrac{\text{Force}}{\text{Area}}$ ($N/mm^2$)

Therefore,

Mean strength $(f_m) = \frac{\sum f_c}{n}$

c. Standard deviation, $S = \sqrt{\frac{\sum(f_c - f_m)^2}{n - 1}}$

where, $f_c$ = compression strength

$f_m$ = mean strength

n = no of cubes

So, for 7 days cube test the density and compressive strength are calculated as follows:

i. For KCl cubes (5 nos):

The corresponding mass of cubes (A, B, C, D & E) obtained are 7.56, 7.38, 7.47, 7.33 and 7.51Kg. Also the corresponding crushing load of cubes (A, B, C, D & E) obtained are 170, 166, 168, 165 and 16,9KN.

The various densities for the cubes are:

Density (cube A) $= \frac{\text{Mass}}{\text{Volume}} = \frac{8.00}{0.00338} = 2366.86Kg/m^3$

Density (cube B) $= \frac{7.92}{0.00338} = 2343.2Kg/m^3$

Density (cube C) $= \frac{7.90}{0.00338} = 2337.29Kg/m^3$

Density (cube D) $= \frac{7.85}{0.00338} = 2322.49Kg/m^3$

Density (cube E) $= \frac{7.89}{0.00338} = 2334.32Kg/m^3$

Also compressive strength (Cube A) $= \frac{Force}{Area}$

$= \frac{170}{22500} = 7.56 \times 10^{-3} KN$

$= 7.56 \times 10^{-3} \times 1000 = 7.56 N/mm^2$

Compressive strength (Cube B) $= \frac{166}{22500} \times 1000 = 7.38 N/mm^2$

Compressive strength (Cube C) $= \frac{168}{22500} \times 1000 = 7.47 N/mm^2$

Compressive strength (Cube D) $= \frac{165}{22500} \times 1000 = 7.33 N/mm^2$

Compressive strength (Cube E) $= \frac{169}{22500} \times 1000 = 7.51 N/mm^2$

Therefore,

Mean strength $= \frac{7.56 + 7.38 + 7.47 + 7.33 + 7.51}{5}$

$= 7.45 N/mm^2$

ii. For Na0H Cubes (5 nos)

The corresponding mass of cubes (A, B, C, D & E) obtained are 7.88, 7.92, 7.75, 7.70, 7.79Kg. Also the corresponding crushing load of cubes (A, B, C, D & E) obtained are 158, 150, 155, 148 and 157KN.

Density (cube A) $\frac{\text{Mass}}{\text{Volume}} = \frac{7.88}{0.00338}$ = 2331.36Kg/m$^3$

Density (cube B) $= \frac{7.92}{0.00338} =$ 2343.19Kg/m$^3$

Density (cube C) $= \frac{7.75}{0.00338} =$ 2292.29Kg/m$^3$

Density (cube D) $= \frac{7.70}{0.00338} =$ 2278.12Kg/m$^3$

Density (cube E) $= \frac{7.79}{0.00338} =$ 2236.69Kg/m$^3$

Also compressive strength (Cube A) = $\frac{\text{Force}}{\text{Area}}$

$= \frac{158}{22500} \times 1000 = 7.02\text{N/mm}^2$

Compressive strength (Cube B) $= \frac{150}{22500} \times 1000 = 6.67\text{N/mm}^2$

Compressive strength (Cube C) $= \frac{155}{22500} \times 1000 = 6.89\text{N/mm}^2$

$$\text{Compressive strength (Cube D)} = \frac{148}{22500} \times 1000 = 6.58\text{N/mm}^2$$

$$\text{Compressive strength (Cube E)} = \frac{157}{22500} \times 1000 = 6.98\text{N/mm}^2$$

$$\text{Mean strength} = \frac{7.02 + 6.67 + 6.89 + 6.58 + 6.98}{5}$$

$$= 6.83\text{N/mm}^2$$

iii For the control cubes (5 Nos)

The corresponding mass of cubes (A, B, C, D & E) obtained are 7.58, 7.51, 7.46, 7.41 and 7.56Kg. Also the corresponding crushing load of cubes (A, B, C, D & E) obtained are 110, 138, 120, 125 and 136KN.

$$\text{Density (cube A)} \quad \frac{\text{Mass}}{\text{Volume}} = \frac{7.58}{0.00338} = 2242.60\text{Kg/m}^3$$

$$\text{Density (cube B)} = \frac{7.51}{0.00338} = 2221.89\text{Kg/m}^3$$

$$\text{Density (cube C)} = \frac{7.46}{0.00338} = 2207.10\text{Kg/m}^3$$

$$\text{Density (cube D)} = \frac{7.41}{0.00338} = 2192.31\text{Kg/m}^3$$

$$\text{Density (cube E)} = \frac{7.56}{0.00338} = 2236.69\text{Kg/m}^3$$

Also compressive strength (Cube A) = $\frac{\text{Force}}{\text{Area}}$

$$= \frac{110}{22500} \times 1000 = 4.89\text{N/mm}^2$$

$$\text{Compressive strength (Cube B)} = \frac{138}{22500} \times 1000 = 6.13\text{N/mm}^2$$

$$\text{Compressive strength (Cube C)} = \frac{120}{22500} \times 1000 = 5.33\text{N/mm}^2$$

$$\text{Compressive strength (Cube D)} = \frac{125}{22500} \times 1000 = 5.56\text{N/mm}^2$$

$$\text{Compressive strength (Cube E)} = \frac{136}{22500} \times 1000 = 6.04\text{N/mm}^2$$

$$\text{Mean strength} = \frac{4.89 + 6.13 + 5.33 + 5.56 + 6.04}{5}$$

$$= 5.59\text{N/mm}^2$$

NB: The same calculation method above is adopted for 14, 21 and 28 days compression test respectively for the determination of density and compressive strength.

$C_{1.}$ Standard deviation(S) for 7 days compression test:

i. For KCl cubes;

Standard deviation, S = $\sqrt{\frac{\sum(f_c - f_m)^2}{n-1}}$

$S = \frac{\sqrt{(0.0354)}}{5-1} = \sqrt{\frac{0.0354}{4}}$

$= 0.09 N/mm^2$

ii. For NaOH cubes;

$S = \sqrt{\frac{0.1503}{4}} = 0.19 N/mm2$

iii For the control cubes;

$S = \sqrt{\frac{0.05026}{4}} = 0.51 N/mm2$

$C_2$. Standard deviation(S) for 14 days compression test:

i. For KCl cubes;

Standard deviation, $S = \sqrt{\frac{1.4485}{4}} = 0.60$

ii. For NaOH cubes;

$S = \sqrt{\frac{3.7808}{4}} = 0.97$

iii.For the Control cubes;

$S = \sqrt{\frac{7.4532}{4}} = 1.37$

$C_3$. Standard deviation(S) for 21 days compression test:

i. For KCl cubes;

Standard deviation, $S = \sqrt{\frac{13.1714}{4}} = 1.81$

ii. For NaOH cubes;

$S = \sqrt{\frac{0.7285}{4}} = 0.43$

iii.For the Control cubes;

$S = \sqrt{\frac{5.4742}{4}} = 1.17$

$C_4$. Standard deviation for 28 days compression test:

i. For KCl cubes;

Standard deviation, $S = \sqrt{\frac{7.3683}{4}} = 1.36$

ii. For NaOH cubes;

$S = \sqrt{\frac{2.0958}{4}} = 0.72$

iii. For the Control cubes;

$S = \sqrt{\frac{2.4439}{4}} = 0.78$

### 3.3.10 PRECAUTIONS

The following precautions were observed during the production of the concrete cubes.

1. The sides of mould were oiled with mineral oil to prevent bonding between the mould and the concrete.
2. The concrete was mixed thoroughly to obtain workable concrete.
3. In instances where the moulds were too full after compaction, care was taken to ensure that the surplus concrete was removed from the moulds with the aid of a float.
4. Care was taken when removing the concrete cubes from the moulds to damage.
5. The concrete cube was properly placed in position on the weighing balance before taken the readings.
6. It was ensured that the compression machine was carefully placed on a flat base to avoid disturbance due to instability.
7. The compression machine was plugged to electricity before loading.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

## 4.1 ANALYSIS OF RESULT

**Table 3: Sieve analysis test result for sand (fine aggregate)**

| Sieve sizes | Weight of sieves(g) | Weight of sieve (g) + sample | Weight retained (g) | % retained | Cumulative % retained | % passing |
|---|---|---|---|---|---|---|
| 5.00mm | 477.9 | 480.88 | 2.98 | 0.3 | 0.3 | 99.7 |
| 3.35mm | 468.35 | 473.1 | 4.75 | 0.47 | 0.77 | 99.23 |
| 2.00mm | 418.06 | 422.1 | 4.04 | 0.4 | 1.17 | 98.83 |
| 1.18mm | 388.90 | 425.06 | 36.16 | 3.62 | 4.79 | 95.21 |
| 850μm | 357.1 | 423.5 | 66.40 | 6.64 | 11.43 | 88.57 |
| 600μm | 338.5 | 450.2 | 111.7 | 11.17 | 22.6 | 77.4 |
| 425μm | 344.4 | 500.3 | 155.9 | 15.59 | 38.19 | 61.81 |
| 300μm | 338.07 | 490.3 | 152.23 | 15.22 | 53.41 | 46.59 |
| 150μm | 305.07 | 605.7 | 300.63 | 30.06 | 83.47 | 16.53 |
| 75μm | 313.1 | 400.01 | 86.91 | 8.69 | 92.16 | 7.84 |
| Pan | 271.9 | 350.22 | 78.32 | 7.83 | 99.99 | 0.0 |
| Total | | | 1000.02 | 100 | | |

**Table 4: Sieve analysis test result for granite(coarse aggregate)**

| Sieve sizes | Weight of sieves(g) | Weight of sieve (g) + sample | Weight retained (g) | % retained | Cumulative % retained | % passing |
|---|---|---|---|---|---|---|
| 20mm | 1476.10 | 1653.10 | 177 | 35.4 | 35.4 | 64.6 |
| 14mm | 1398.95 | 1514.71 | 115.76 | 23.15 | 58.55 | 41.45 |
| 10mm | 1349.2 | 1400.10 | 50.9 | 10.18 | 68.73 | 31.27 |
| 5mm | 1497.4 | 1603.5 | 106.1 | 21.22 | 89.95 | 10.05 |
| 3.35mm | 1345.15 | 1390.6 | 45.45 | 9.09 | 99.04 | 0.96 |
| 425 μm | 958.6 | 963.1 | 4.5 | 0.9 | 99.94 | 0.06 |
| Pan | 808.7 | 808.99 | 0.29 | 0.058 | 100 | 0.0 |
| Total | | | 500 | 100 | | |

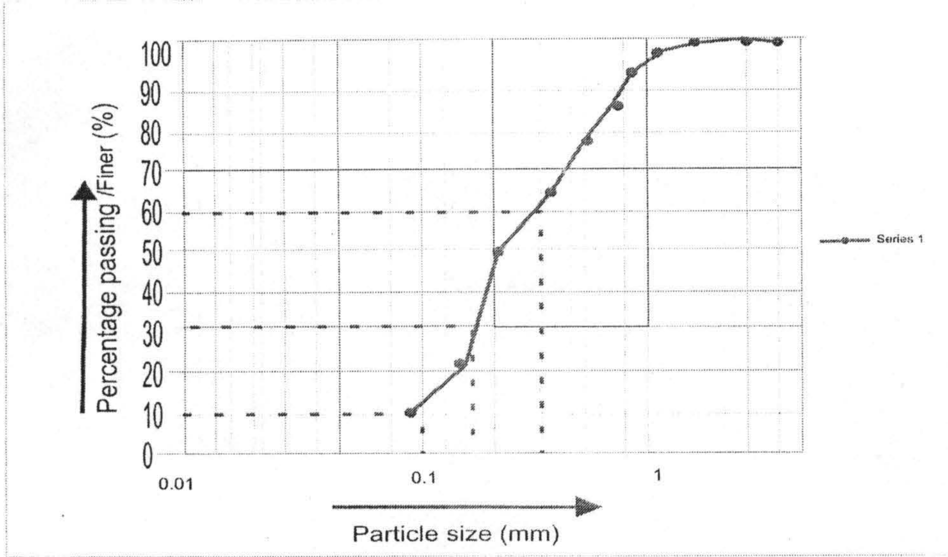


Figure 1: Sieve analysis distribution curve for sand

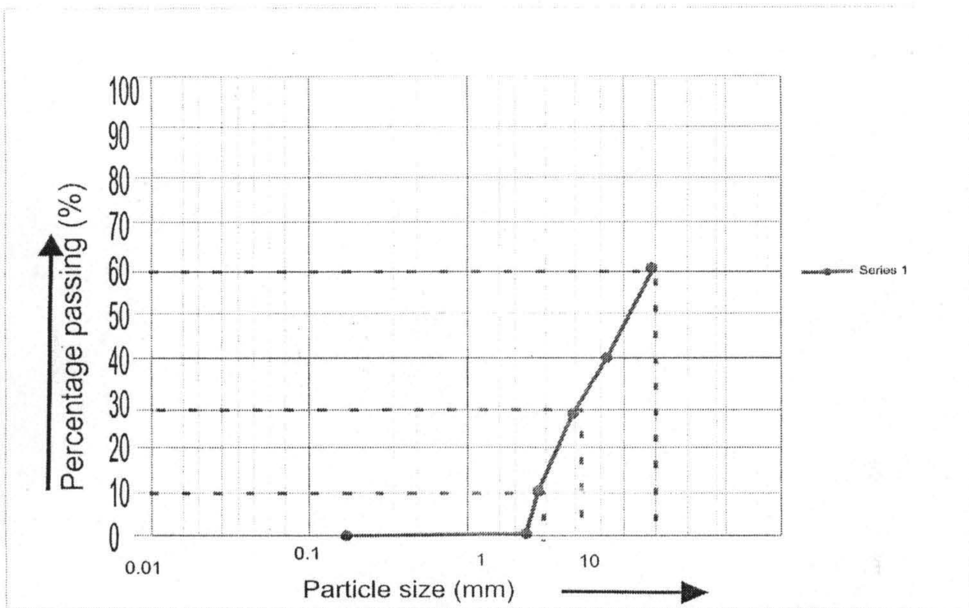


Figure 2: Sieve analysis distribution curve for granite

**For Sand**

$D_{60}$ = 0.425mm

$D_{30}$ = 0.2mm

$D_{10}$ = 0.1mm

Coefficient of uniformity is given as, $C_u = \frac{D_{60}}{D_{10}}$ ..................................10

where, $D_{60}$ = Particle size such that 60% of the soil is finer than this size

$D_{10}$ = Particle size such that 10% of the soil is finer than this size

$$C_u = \frac{0.4}{0.1} = 4$$

Since, the larger the numerical value of $C_u$, the more is the range of particles. And our $C_u$ is 4. Therefore the sand is well graded.

The general shape of the particle size distribution curve is described by another coefficient known as the coefficient of curvature ($C_c$) or the coefficient of gradation ($C_g$)

$$C_c = \frac{(D_{30})^2}{D_{10} x D_{60}} \quad \text{.......................................................11}$$

$D_{30}$ is the particle size such that 30% of the soil is finer than this size

$$C_c = \frac{(0.2)^2}{0.1x0.4} = \frac{0.04}{0.04} = 1$$

The $C_c$ of 1 shows that the curve is a flat s – curve and the soil is well graded.

**For granite**

$D_{60}$ = 20mm

$D_{30}$ = 10mm

$D_{10}$ = 5mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{20}{5} = 4$$

Therefore the granite is well graded.

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{10^2}{5 \times 20} = \frac{100}{100} = 1$$

It shows that the particle size distribution curve is well spread out (flat s - curve) and therefore the grante is well graded (because it contains particles of different sizes in good proportion).

**Table 5: Specific Gravity Result for Fine Aggregate**

| Bottle No | 1 | 2 | 3 |
|---|---|---|---|
| Weight of Bottle ($W_1$)g | 247.60g | 247.30g | 98.80g |
| Weight of Bottle + Sample ($W_2$)g | 130.90g | 123.30g | 62.90g |
| Weight of Bottle + Sample + Water ($W_3$)g | 366.00g | 155.60g | 360.60g |
| Weight of Bottle + Water (full) ($W_4$)g | 356.40g | 345.00g | 145.60g |
| Weight of addition of Water ($W_4 - W_1$)g | 118.40g | 99.70g | 48.80g |
| Weight of added Soil ($W_3 - W_2$)g | 235.10g | 237.30g | 92.70g |
| Weight of Sample ($W_2 - W_1$)g | 32.10g | 26.40g | 16.10g |
| Weight of Water Displaced by Sample ($W_1$) – ($W_3 - W_2$)g | 12.50g | 10.00g | 6.1g |
| Specific Gravity of Sample ($W_2 - W_1$)/W | 2.57 | 2.64 | 2.59 |
| Average Specific Gravity | | 2.60 | |

**Table 6: Specific Gravity Result for Coarse Aggregate**

| **Bottle No** | **1** | **2** | **3** |
|---|---|---|---|
| Weight of Bottle ($W_1$)g | 632.10g | 631.60g | 632.20g |
| Weight of Bottle + Sample ($W_2$)g | 917.40g | 978.50g | 956.18g |
| Weight of Bottle + Sample + Water ($W_3$)g | 1798.80g | 1833.40g | 1822.70g |
| Weight of Bottle + Water (full) ($W_4$)g | 1626.43g | 1620.70g | 1624.50g |
| Weight of addition of Water ($W_4 - W_1$)g | 994.33g | 989.10g | 992.30g |
| Weight of added Soil ($W_3 - W_2$)g | 881.43g | 854.90g | 866.52g |
| Weight of Sample ($W_2 - W_1$)g | 295.30g | 346.90g | 323.98g |
| Weight of Water Displaced by Sample ($W_1$) – ($W_3 - W_2$)g | 112.93g | 134.20g | 125.78g |
| Specific Gravity of Sample ($W_2 - W_1$)/W | 2.61 | 2.58 | 2.58 |
| Average Specific Gravity | | 2.59 | |

**Table 7: Bulk density Result for fine aggregates**

| | Un-compacted | | | Compacted | | |
|---|---|---|---|---|---|---|
| **Test** | **1** | **2** | **3** | **1** | **2** | **3** |
| Weight of Sample Divider (W)g | 1561.40 | 1561.40 | 1561.40 | 1561.40 | 1561.40 | 1561.40 |
| Weight of Sample Divider + Weight of Material ($W_2$)g | 5356.14 | 5530.24 | 5523.68 | 6056.38 | 6146.20 | 6147.52 |
| Weight of Material ($W_2 - W_1$) ($W_3$)g | 3794.74 | 3968.84 | 3962.28 | 4494.98 | 4584.80 | 4586.12 |
| Volume of Sample Divider V ($m^3$) | 3237.60 | 3237.60 | 3237.60 | 3237.60 | 3237.60 | 3237.60 |
| Bulk Density $W_3/V$ ($Kg/m^3$) | 1172.80 | 1225.83 | 1223.83 | 1388.37 | 1416.11 | 1416.62 |
| Mean Bulk Density ($Kg/m^3$) | 11207.26 | | | 1407.00 | | |

$$\text{Ratio} = \frac{\text{loose bulk density}}{\text{Compacted bulk density}} = \frac{1207.26}{1407.00} = 0.86$$

**Table 8: Bulk density Result for coarse aggregate**

| | Un-compacted | | | Compacted | | |
|---|---|---|---|---|---|---|
| **Test** | **1** | **2** | **3** | **1** | **2** | **3** |
| Weight of Sample Divider (W)g | 1561.40 | 1561.40 | 1561.40 | 1561.40 | 1561.40 | 1516.40 |
| Weight of Sample Divider + Weight of Material ($W_2$)g | 4945.80 | 4964.26 | 4961.60 | 5548.08 | 5352.75 | 5372.14 |
| Weight of Material ($W_2 - W_1$) ($W_3$)g | 3384.40 | 3402.86 | 3400.20 | 3986.68 | 3791.35 | 3810.64 |
| Volume of Sample Divider V ($m^3$) | 3237.60 | 3237.60 | 3237.60 | 3237.60 | 3237.60 | 3237.60 |
| Bulk Density $W_3/V$ ($Kg/m^3$) | 1045.34 | 1051.04 | 1050.22 | 1231.37 | 1171.04 | 1177.00 |
| Mean Bulk Density ($Kg/m^3$) | 1048.87 | | | 1193.14 | | |

$$\text{Ratio} = \frac{\text{loose bulk density}}{\text{Compacted bulk density}} = \frac{1048.87}{1193.14} = 0.88$$

**Table 9: Moisture content Result for fine aggregate**

| Number of can | D9 | P5 | B1 |
|---|---|---|---|
| Weight of empty can (W)g | 23.30g | 23.00g | 24.50g |
| Weight of can + weight sample ($W_1$)g | 60.40g | 68.80g | 68.80g |
| Weight of can + oven dried sample ($W_2$)g | 60.20g | 68.50g | 60.50g |
| Weight of water Ww = ($W_1 - W_2$)g | 0.20g | 0.30g | 0.30g |
| Weight of dried sample $W_d$ = ($W_2$ – W)g | 36.90g | 45.50g | 36.00g |
| % moisture content (%Mc)= $W_w$ = ($W_w/W_d$) x 100 | 0.54 | 0.66 | 0.83 |
| Mean % MC | | 0.68 | |

**Table 10: Moisture content result for coarse aggregate**

| Number of can | M5 | U1 | M14 |
|---|---|---|---|
| Weight of empty can (W)g | 23.40g | 24.30 | 25.00g |
| Weight of can + weight sample ($W_1$)g | 83.30g | 85.70g | 83.40g |
| Weight of can + oven dried sample ($W_2$)g | 83.10g | 85.60g | 83.20 |
| Weight of water $W_w$ = ($W_1 - W_2$)g | 0.20g | 0.10g | 0.20g |
| Weight of dried sample $W_d$ = ($W_2$ – W)g | 59.70g | 61.30g | 58.20g |
| % moisture content (%Mc)= $W_w$= ($W_w/W_d$) x 100 | 0.35 | 0.16 | 0.34 |
| Mean % MC | | 0.28 | |

**Table 11: Absorption test Result for coarse aggregate**

| Number of can | 1 | 2 | 3 |
|---|---|---|---|
| Weight of pan + sample ($W_1$)g | 132.4g | 126.9g | 145.6g |
| Weight of pan + oven dry aggregate ($W_2$)g | 132.0g | 126.2g | 140.0g |
| Weight of water ($W_1 - W_2$)g | 0.40g | 0.70g | 0.60g |
| Water absorption $W_1g - W_2g/W_2 \times 100$ | 0.30 | 0.55 | 0.41 |
| Mean % WA | | 0.43 | |

## 4.2 Void Ratio Result

Considering the result obtained from above, the void ratio of the materials can be Calculate as; Void ratio =

$$1 - \left(\frac{\text{Bulk density}}{\text{Specific gravity xunit weight of water}}\right) \quad \text{. . . . from equ 5}$$

Where; unit weight of water = 1000kg/m$^3$

Void ratio result:

First trial for coarse aggregate (un-compacted);

$$\text{Void ratio} = \text{V.R} = 1 - \frac{1045.34}{2.59 \text{ x}1000}$$

$$= \quad 1 - \frac{1045.34}{2590} = 0.59$$

Second trial for coarse aggregate;

$$\text{Void ratio} = \text{V.R} = 1 - \frac{1051.04}{2.59 \text{ x}1000}$$

$$= 1 - \frac{1051.04}{2590} = 0.59$$

Third trial for coarse aggregate;

$$\text{Void ratio} = \text{V.R} = 1 - \frac{1052.22}{2.59 \text{ X } 1000}$$

$$V.R = 1 - \frac{1050.22}{2590} = 0.59$$

$$\text{Average void ratio} = \frac{0.59 + 0.59 + 0.59}{3} = 0.59$$

### 4.3 Porosity Test Result

Considering the result obtained from table of bulk density test, the percentage porosity can be calculated;

Percentage porosity = (1 - E/S) x 100 ..........................from equ 6

where;

E = un-compacted bulk density

S = compacted bulk density

Porosity result for coarse aggregate:

Fist trial;

$$\text{Percentage porosity} = (1 - \frac{1172.08}{1388.34}) \times 100\% = 15.58\%$$

Second trial;

$$\text{Percentage porosity} = (1 - \frac{1225.83}{1416.11}) \times 100\% = 13.43\%$$

Third trial;

$$\text{Percentage porosity} = (1 - \frac{1223.83}{1416.52}) \times 100\% = 13.60\%$$

$$\text{Average percentage porosity} = \frac{15.58 + 13.43 + 13.60}{3} = 14.20\%$$

### 4.4 Compacting Factor Test Result

Compacting factor test is the degree of compaction which is measured by the density ratio,that is the ratio of the density actually achieved in the test to the density of the same fully compacted.

Compacting factor = $\frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}}$ ....................from equ 8

where;

Weight of partially compacted concrete = (weight of mould + partially compacted Concrete) – (weight of mould)

Weight of fully compacted concrete = (weight of mould + fully compacted Concrete) – (weight of mould)

Where; weight of mould = 1.426kg

(i) Potassium chloride cube, 0.5 water/cement ratio:

First Trail;

Weight of fully compacted concrete = (1.426 + 12.032) – 1.426

= (13.458 – 1.426) = 12.032Kg

Weight of fully compacted concrete = (1.426 + 14.102) – 1.426

= (15.528 – 1.426)

= 14.102Kg

Compacting factor = $\frac{12.032}{14.102}$ = 0.85

Second Trial;

Weight of partially compacted concrete = (1.426 + 12.063) – 1.426

= (13.489 – 1.426) = 12.063Kg

Weight of fully compacted concrete = (1.426 + 14.204) – 1.426

= (15.63 – 1.426) = 14.204Kg

Compacting factor = $\frac{12.063}{14.204}$ = 0.85

Third Trial;

Weight of partially compacted concrete = (1.426 + 12.105) – 1.426

= (13531 – 1.426) = 12.105Kg

Weight of fully compacted concrete = (1.426 + 14.530) – 1.426

= (15.956 – 1.426) = 14.530Kg

Compacting factor = $\frac{12.105}{14.530}$ = 0.83

Average compacting factor = $\frac{0.85 + 0.85 + 0.83}{3}$ = 0.84

(ii) Caustic soda cube, 0.5 water/cement ratio:

First Trial;

Weight of partially compacted concrete = (1.426 + 12.201) – 1.426

= (13 . 627 – 1.426) = 12.20Kg

Weight of fully compacted concrete = (1.426 + 14.150) – 1.426

= (15.576 – 1.426) = 14.15Kg

Compacting factor = $\frac{12.201}{14.15}$ = 0.86

Second Trail;

Weight of partially compacted concrete = (1.426 + 12.221) – 1. 426

= (13.647 – 1.426) = 12.221Kg

Weight of fully compacted concrete = (1.426 + 14.263) – 1.426

= (15.689 – 1 . 426) = 14.263Kg

Compacting factor = $\frac{12.221}{14.263}$ = 0.86

Third Trial;

Weight of fully compacted concrete = (1.426 + 14.384) – 1.426

= (15.810 – 1.4260) = 14.384

Weigh of fully compacted concrete = (1.426 + 14.384) – 1.426

= (15.810 – 1.426) = 14.384

Compacting factor = $\frac{12.254}{14.384}$ = 0.85

Average compacting factor = $\frac{0.86 + 0.86 + 0.85}{3}$

= 0.86

(iii) Control cubes, 0.5 water cement ratio:

First Trial;

Weight of partially compacted concrete = (1.426 + 12.002) – 1.426

= (13.428 – 1.426) = 12.002Kg

Weight of fully compacted concrete = (1.426 + 14.112) – 1.426

= (15.538 – 1.426) = 14.112Kg

Compacting factor = $\frac{12.002}{14.112}$ = 0.85

Second Trail;

Weight of partially compacted concrete = (1.426 + 12.802) – 1.426

= (14.228 – 1.426) = 12.802Kg

Weight of fully compacted concrete = (1.426 + 14.352) - 1.426

= (15.779 – 1.426) = 14.352Kg

Compacting factor = $\frac{12.802}{14.352}$ = 0.89

Third Trial;

Weight of partially compacted concrete = (1.426 + 12.553) – 1.426

= (13.979 – 1.426) = 12.553Kg

Weigh of fully compacted concrete = (1.426 + 14. 333) – 1. 426

= (15.759 – 1.426) = 14.333Kg

Compacting factor = $\frac{12.553}{14.333}$ = 0.87

Average compacting factor = $\frac{0.86 + 0.89 + 0.87}{3}$

= 0.87

## 4.5 Slump Test Result

(i.) Potassium chloride cubes:

Water/cement ratio = 0 5

Height of the cone = 310mm

First rail: slump height = 18.3mm

Second trail: slump height = 20mm

Third trail: Slump height = 21mm

Average = $\frac{18.3 + 20 + 21}{3}$ = 19.76mm

(ii) Caustic Soda cubes:

Water/cement ratio = 0.5

Height of cone = 310mm

First trail: slump height = 19.10mm

Second trial: Slump height = 21.05mm

Third trial: Slump height = 22.00mm

Average = $\frac{19.10 + 21.05 + 22.00}{3}$ = 20.72mm

(iii) Control Cubes:

Water/cement ratio = 0.5

Height of cone = 310mm

First trail: Slump height = 21mm

Second trail: Slump height = 20mm

Third trial: Slump height = 23mm

$$\text{Average} = \frac{21 + 20 + 23}{3} = 21.33\text{mm}$$

## 4.6 Compressive Strength Test Results

**Table 12: 7 – Days compressive strengths of concrete**

| Concrete Cube | Cube no | Date of casting | Date of crushing | Age (days) | Mass of cube (Kg) | Density ($kg/m^3$) | Crushing Load (KN) | Compressive Strength ($N/mm^2$) $f_c$ | Mean strength ($N/mm^2$) $f_m$ |
|---|---|---|---|---|---|---|---|---|---|
| KCl | A | 16\03\11 | 23\03\11 | 7 | 8.00 | 2366.86 | 170 | 7.56 | |
| | B | " | " | " | 7.92 | 2343.20 | 166 | 7.38 | 7.45 |
| | C | " | " | " | 7.90 | 2337.29 | 168 | 7.47 | |
| | D | " | " | " | 7.85 | 2322.49 | 165 | 7.33 | |
| | E | " | " | " | 7.89 | 2334.32 | 169 | 7.51 | |
| NaOH | A | " | " | " | 7.88 | 2331.36 | 158 | 7.02 | |
| | B | " | " | " | 7.92 | 2343.19 | 150 | 6.67 | 6.83 |
| | C | " | " | " | 7.75 | 2292.89 | 155 | 6.89 | |
| | D | " | " | " | 7.70 | 2278.12 | 148 | 6.58 | |
| | E | " | " | " | 7.79 | 2304.73 | 157 | 6.98 | |
| Control | A | " | " | " | 7.58 | 2242.60 | 110 | 4.89 | |
| | B | " | " | " | 7.51 | 2221.89 | 138 | 6.13 | 5.59 |
| | C | " | " | " | 7.46 | 2207.10 | 120 | 5.33 | |
| | D | " | " | " | 7.41 | 2192.31 | 125 | 5.56 | |
| | E | " | " | " | 7.56 | 2236.69 | 136 | 6.04 | |

**Table 13: Standard deviation for concrete cubes at 7 - days**

| Concrete Cube | Cube No | $f_m$ | $f_c$ | $f_c - f_m$ | $(f_c-f_m)^2$ |
|---|---|---|---|---|---|
| KCl | A | | 7.56 | 0.11 | 0.0121 |
| | B | | 7.38 | -0.07 | 0.0049 |
| | C | 7.45 | 7.47 | 0-02 | 0.0004 |
| | D | | 7.33 | -0.12 | 0.0144 |
| | E | | 7.51 | 0.06 | 0.0036 |
| | | | | ∑= 0 | ∑= 0.0354 |
| NaOH | A | | 7.02 | 0.19 | 0.0361 |
| | B | | 6.67 | -0.16 | 0.0256 |
| | C | 6.83 | 6.89 | 0.06 | 0.0036 |
| | D | | 6.58 | -0.25 | 0.0625 |
| | E | | 6.98 | 0.15 | 0.0225 |
| | | | | ∑ = 0 | ∑= 0.1503 |
| Control | A | | 4.89 | -0.70 | 0.4900 |
| | B | | 6.13 | 0.54 | 0.2916 |
| | C | 5.59 | 5.33 | -0.26 | 0.0676 |
| | D | | 5.56 | -0.03 | 0.0009 |
| | E | | 6.04 | 0.45 | 0.2025 |
| | | | | ∑= 0 | ∑= 1.0526 |

## Table 14: 14 - Days compressive strengths of concrete

| Concrete Cube | Cube no | Date of casting | Date of Crushing | Age (days) | mass of cube (kg) | Density ($kg/m^3$) | Crushing Load (KN) | Compressive Strength ($N/mm^2$) $f_c$ | Mean Strength ($N/mm^2$) $f_m$ |
|---|---|---|---|---|---|---|---|---|---|
| KCl | A | 16\03\11 | 30\03\11 | 14 | 8.02 | 2372.78 | 180 | 8.00 | |
| | B | " | " | " | 7.93 | 2346.15 | 184 | 8.18 | |
| | C | " | " | " | 8.00 | 2366.86 | 170 | 7.56 | 8.16 |
| | D | " | " | " | 8.08 | 2390.53 | 206 | 9.16 | |
| | E | " | " | " | 7.96 | 2355.03 | 178 | 7.91 | |
| NaOH | A | " | " | " | 7.84 | 2319.53 | 100 | 4.44 | |
| | B | " | " | " | 8.01 | 2369.82 | 80 | 3.56 | |
| | C | " | " | " | 8.08 | 2390.53 | 50 | 2.22 | 3.51 |
| | D | " | " | " | 8.02 | 2372.78 | 100 | 4.44 | |
| | E | " | " | " | 7.94 | 2349.11 | 65 | 2.89 | |
| Control | A | " | " | " | 7.68 | 2272.20 | 184 | 8.18 | |
| | B | " | " | " | 7.67 | 2269.23 | 117 | 5.20 | |
| | C | " | " | " | 7.47 | 2210.06 | 111 | 4.93 | 5.8 |
| | D | " | " | " | 7.36 | 2177.51 | 130 | 5.78 | |
| | E | " | " | " | 7.42 | 2195.27 | 112 | 4.98 | |

**Table 15: Standard deviation for concrete cubes at 14 - days**

| Concrete Cube | Cube No | $f_m$ | $f_c$ | $f_c$-$f_m$ | $(f_c-f_m)^2$ |
|---|---|---|---|---|---|
| KCl | A | 8.16 | 8.00 | -0.16 | 0.0256 |
| | B | | 8.18 | 0.02 | 0.0004 |
| | C | | 7.56 | -0.6 | 0.3600 |
| | D | | 9.16 | 1.0 | 1.0000 |
| | E | | 7.91 | -0.25 | 0.0625 |
| | | | | ∑= 0.01 | ∑= 1.4485 |
| NaOH | A | 3.51 | 4.44 | 0.93 | 0.8649 |
| | B | | 3.56 | 0.05 | 0.0025 |
| | C | | 2.22 | -1.29 | 1.6641 |
| | D | | 4.44 | 0.93 | 0.8649 |
| | E | | 2.89 | -0.62 | 0.3844 |
| | | | | ∑= 0 | ∑= 3.7808 |
| Control | A | 5.81 | 8.18 | 2.37 | 5.6169 |
| | B | | 5.20 | -0.61 | 0.3721 |
| | C | | 4.93 | -0.88 | 0.7744 |
| | D | | 5.78 | -0.03 | 0.0009 |
| | E | | 4.98 | -0.83 | 0.6889 |
| | | | | ∑= 0.02 | ∑= 7.4532 |

## Table 16: 21 – Days compressive strengths of concrete

| Concrete Cube | Cube no | Date of casting | Date of crushing | Age (days) | Mass of cube (kg) | Density ($kg/m^3$) | Crushing Load (KN) | Compressive Strength ($N/mm^2$) $f_c$ | Mean Strength ($N/mm^2$) $f_m$ |
|---|---|---|---|---|---|---|---|---|---|
| KCl | A | 16/03/11 | 06/04/11 | 21 | 0.03 | 8.8757 | 156 | 6.93 | |
| | B | " | " | " | 8.00 | 2366.86 | 256 | 11.38 | |
| | C | " | " | " | 7.67 | 2269.23 | 176 | 7.82 | 8.40 |
| | D | " | " | " | 8.15 | 2411.24 | 197 | 8.76 | |
| | E | " | " | " | 8.10 | 2396.45 | 160 | 7.11 | |
| NaOH | A | " | " | " | 7.90 | 2337.28 | 80 | 3.56 | |
| | B | " | " | " | 8.12 | 2402.37 | 90 | 4.00 | |
| | C | " | " | " | 7.49 | 2215.98 | 106 | 4.71 | 4.02 |
| | D | " | " | " | 7.78 | 2301.78 | 90 | 4.00 | |
| | E | " | " | " | 7.65 | 2263.31 | 86 | 3.82 | |
| Control | A | " | " | " | 7.59 | 2245.56 | 190 | 8.44 | |
| | B | " | " | " | 7.68 | 2272.19 | 135 | 6.00 | |
| | C | " | " | " | 7.79 | 2304.73 | 138 | 6.13 | 6.38 |
| | D | " | " | " | 7.40 | 2189.35 | 128 | 5.69 | |
| | E | " | " | " | 7.47 | 2210.06 | 127 | 5.64 | |

## Table 17: Standard deviation for concrete cubes at 21 - days

| Concrete Cube | Cube No | $f_m$ | $f_c$ | $f_c - f_m$ | $(f_c - f_m)^2$ |
|---|---|---|---|---|---|
| KCl | A | | 6.93 | -1.47 | 2.1609 |
| | B | 8.40 | 11.38 | 2.98 | 8.8804 |
| | C | | 7.82 | -0.58 | 0.3364 |
| | D | | 8.76 | 0.36 | 0.1296 |
| | E | | 7.11 | -1.29<br>∑= 0 | 1.6641<br>∑= 13.1714 |
| NaOH | A | | 3.56 | -0.46 | 0.2116 |
| | B | 4.02 | 4.00 | -0.002 | 0.0004 |
| | C | | 4.71 | 0.69 | 0.4761 |
| | D | | 4.00 | -0.002 | 0.0004 |
| | E | | 3.82 | -0.2<br>∑= 0.026 | 0.04<br>∑ = 0.7285 |
| Control | A | | 8.44 | 2.06 | 4.2436 |
| | B | 6.38 | 6.00 | -0.38 | 0.1444 |
| | C | | 6.13 | -0.25 | 0.0625 |
| | D | | 5.69 | -0.69 | 0.4761 |
| | E | | 5.64 | -0.74<br>∑= 0 | 0.5476<br>∑= 5.4742 |

## Table 18: 28 – Days compressive strengths of concrete

| Concrete Cube | Cube No | Date of casting | Date of crushing | Age (days) | Mass of cube (kg) | Density (kg/m³) | Crushing Load (KN) | Compressive Strength (N/mm²) $f_c$ | Mean Strength (N/mm²) $f_m$ |
|---|---|---|---|---|---|---|---|---|---|
| KCl | A | 16/03/11 | 13/04/11 | 28 | 8.12 | 2402.37 | 196 | 8.71 | |
| | B | " | " | " | 8.06 | 2384.62 | 263 | 11.69 | |
| | C | " | " | " | 7.74 | 2289.94 | 230 | 10.22 | 9.58 |
| | D | " | " | " | 8.22 | 2431.95 | 194 | 8.62 | |
| | E | " | " | " | 7.76 | 2295.86 | 195 | 8.67 | |
| NaOH | A | " | " | " | 8.12 | 2402.37 | 102 | 4.53 | |
| | B | " | " | " | 8.23 | 2434.91 | 122 | 5.42 | |
| | C | " | " | " | 7.58 | 2242.60 | 80 | 3.56 | 4.28 |
| | D | " | " | " | 7.84 | 2319.53 | 90 | 4.00 | |
| | E | " | " | " | 7.78 | 2301.78 | [illegible] | 3.91 | |
| Control | A | " | " | " | 7.89 | 2334.32 | 158 | 7.02 | |
| | B | " | " | " | 7.88 | 2331.36 | 168 | 7.47 | |
| | C | " | " | " | 8.04 | 2378[illegible] | 170 | 7.56 | 6.80 |
| | D | " | " | " | 7.96 | 23[illegible].03 | 132 | 5.87 | |
| | E | " | " | " | 7.69 | [illegible]275.15 | 137 | 6.09 | |

**Table 19: Standard deviation for concrete cubes at 28 - days**

| Concrete Cube | Cube No | $f_m$ | $f_c$ | $f_c - f_m$ | $(f_c - f_m)^2$ |
|---|---|---|---|---|---|
| KCl | A | | 8.71 | -0.87 | 0.7569 |
| | B | 9.58 | 11.69 | 2.11 | 4.4521 |
| | C | | 10.22 | 0.64 | 0.4096 |
| | D | | 8.62 | -0.96 | 0.9216 |
| | E | | 8.67 | -0.91 | 0.8281 |
| | | | | $\sum = 0.01$ | $\sum = 7.3683$ |
| NaOH | A | | 4.53 | 0.25 | 0.0625 |
| | B | 4.28 | 5.42 | 1.14 | 1.2996 |
| | C | | 3.56 | -0.72 | 0.5184 |
| | D | | 4.00 | -0.28 | 0.0784 |
| | E | | 3.91 | -0.37 | 0.1369 |
| | | | | $\sum = 0.02$ | $\sum = 2.0958$ |
| Control | A | | 7.02 | 0.22 | 0.0484 |
| | B | 6.80 | 7.47 | 0.67 | 0.4489 |
| | C | | 7.56 | 0.76 | 0.5776 |
| | D | | 5.87 | -0.93 | 0.8649 |
| | E | | 6.09 | -0.71 | 0.5041 |
| | | | | $\sum = 0.01$ | $\sum = 2.4439$ |

## 4.7 DISCUSSION OF RESULT

### Sieve Analysis:

The result of sieve is shown in table 3 and 4 from the sieve results and particle distribution curve, the fine aggregate particles falls within the fine gravel fraction and fine sand fraction, and this indicates well graded filler in concrete mix design. The coarse aggregate practices fal! within the coarse and medium gravel fraction with fine sand fraction according to BS 882 (Neille 2000).

**Specific Gravity:**

The result of specific gravity of the aggregate sample is shown in table 5 and 6. The values of the average specific gravity for the fine and coarse aggregate obtained are 2.60 and 2.59 falling within the standard average specific gravity for various rock groups between 2.57 for (flint) to 2.80 for (Basalt).

**Bulk Density:**

The result of bulk density is shown in table 7 and 8. The test result gave an average of 1048.kg/m$^3$ and 1193.14kg/m$^3$ for un-compacted and compacted coarse aggregate. A density ratio of 0.88 was obtained which is an indication of averagely densed material used for concrete production. This falls within unit standard (0.87 – 0.96). Also average of 1207.26kg/m$^3$ and 1047.00kg/m$^3$ were obtained for un-compacted and compacted fine aggregate. But density ratio obtained of 0.86 falls outside the limit which usually lies between 0.87 and 0.9 (Neille, 2000).

**Moisture Content:**

The result of moisture content is shown in table 9 and 10 for fine and coarse aggregate. Both the results of fine and coarse aggregate indicate that they consist relatively low moisture of less than 1% and hence require more water to compensate the amount required to attain saturation and workable mix. This requirement is calculated and catered for (Water adjustment in mix design).

**Absorption Test:**

The result of absorption test is shown in table 11. The result for coarse aggregate gave average of 0.43% which shown an indication of very low absorption ability and hence has the tendency of minimizing volume change of the entire concrete due to its poor absorption ability.

**Void Ratio:**

As shown in article 4.2. The void ratio result gave an average of 0.59 for coarse aggregate: This shows relatively low spaces within the mass of material used for casting. Hence the result indicates that the moderate amount of cement and coarse aggregate were used in making the concrete.

**Porosity:**

As shown in article 4.3. Porosity result gave an average of 14.20 for coarse aggregate which is an indication of the pores within the aggregate. Aggregate with high porosity will tend to produce a less durable concrete particularly when subjected to freezing and thawing than an aggregate with low porosity.

**Slump Test:**

The slump test result gave an average of 19.76mm for concrete with Potassium chloride, 20.72mm for concrete with Caustic soda and 21.33mm for the Control concrete. Thus the concrete produced can be said to possess low workability, which is as a result of specified water – cement ratio used for the mix.

**Compacting Factor Test:**

The compacting factor result gave an average of 0.84 for the concrete produced with Potassium chloride, 0.86 for the concrete produced with Caustic soda and 0.87 for the Control concrete, which is also a manifestation of low workability. This can be attributed to minimum mixing water used.

**Compressive Strength Test:**

The concrete cubes produced exhibit some varying characteristic behavior as regards to the setting time on the three different mixes. The Potassium chloride

(KCl) concrete cubes took a longer time to set i.e 2hrs after casting and so it retards the setting time. The Caustic soda (NaOH) concrete cubes took a shorter time to set i.e 1hr after casting and so it accelerates the setting time. While the Control concrete cubes take a normal time of 1hr 20mins to set after casting.

It is well known that variations could occur in the strength of the tested concrete cubes due to a variety of factors which include;

1. Age of the concrete
2. Effect of admixtures
3. Efficiency of mixing
4. Quality of materials
5. Proportioning of mixing

From the compression test performed(tables12, 14, 16 & 18) , there were variations in the strength of the concretes cubes at every particular age due to the effects of admixture. It was found that Potassium Chloride (KCl) concrete cubes gained the highest strength progressively as the age increased and this increase in strength is directly proportional to its setting time. Also, the Caustic Soda (NaOH) concrete cubes decreased in strength drastically at the earlier age and then increases at very slow pace as the age increased and this lower increase in strength is not directly proportional to its setting time. The Control concrete cube gained a higher strength progressively than the Caustic Soda cube as the age increased and this being without admixture yielded the normal nature of concrete.

Potassium chloride retards both the initial and final set of the concrete mix as a result of its base chemical. A beneficial side effect of retardation of initial and final sets is an increase in the compressive strength of the concrete. Caustic soda reduced the water content in the concrete mix during the chemical hydration reaction, thereby yielding a low workability and slump test result which lead to a low compressive strength result.

The corresponding mean strengths of the different concrete cubes with respect to their days of curing (i.e. 7, 14, 21 and 28 day) are 7.45N/mm$^2$, 8.16N/mm$^2$, 8.40N/mm$^2$ & 9.58N/mm$^2$ for Potassium Chloride while 6.83N/mm$^2$, 3.51N/mm$^2$, 4.02N/mm$^2$ & 4.28N/mm$^2$ for Caustic Soda and 5.59N/mm$^2$, 5.81N/mm$^2$, 6.38N/mm$^2$ & 6.80N/mm$^2$ for Control concrete respectively. These deduce that the Potassium Chloride cube has the highest strength followed by the Control concrete cube and the Caustic Soda cube has the lowest strength.

# CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATIONS

### 5.1 CONCLUSION

Having carried out the effect of admixture on the properties of concrete, the following conclusions can be drawn based on the test conducted and results obtained.

1. Potassium chloride admixture accelerates the strength of concrete because of its base chemical effects yielding the highest compressive strength of $9.58 N/mm^2$ at the $28^{th}$ day.
2. Caustic soda admixture increases the strength of concrete at a very slow pace as the age increases, yielding the lowest compressive strength of $4.28 N/mm^2$ at the 28th day. This is because of the low workability of the concrete as a result of its chemical hydration reaction which reduces the water content in the concrete.
3. The Sieve analysis result shows that both fine aggregate and coarse aggregate are well graded.
4. The specific gravity test for fine and coarse aggregates fall within the standard average specific gravity for various rock groups between 2.57 to 2.80.
5. The Bulk density test result for coarse aggregates obtained fall within the standard bulk density(0.87 to 0.96), while that of fine aggregate fall outside this limit.

## 5.2 RECOMMENDATION

Based on the test results obtained, it is recommended that Potassium chloride admixture should be used in concrete production. Its use can facilitate both time delivery of project and its quality especially in concrete factories where precast elements are massively produced.

Admixtures can also be used in construction projects situated in water – logged areas and inclement weather environments.When using admixtures in concrete production, they should not be exposed before batching and mixing.

A well graded aggregate consist of aggregates of different sizes which form strong bound and make the final concrete to be strong and dense. Therefore, the use of well graded aggregates is necessary for producing strong concrete.

This study is recommended for further investigation on other class of admixtures with a view to acquiring more detailed and specific information as regard to strength and other properties of structural elements.

## GLOSSARY

1. Admixture : This is anything other than Portland cement, water, and aggregate that is added to a concrete mix to modify its properties.

2. Aggregate : Aggregate is an insoluble non-cementitious particules such as natural sand, gravel, crushed rock or mixture of these materials which are mixed with cement and water to produce concrete

3. Batching : The process of measuring the proportions of the constituent materials before being used.

4. Cement : Is described as a material with adhesive and cohesive properties which makes it capable of bonding mineral fragment into a compact whole.

5. Compaction: Is the process of releasing the air which is trapped in concrete when it is placed so as to obtain maximum density.

6. Concrete: Is a construction material, which consists essentially of a binding agent and mineral filler.

7. Segregate: This is the mechanical resorting of the concrete into its constituent parts

8. Setting: The process in a cement mixed with water during which the paste gradually changes with time from a fluid state into a solid state mainly due to moisture loss.

9. Workability: This expresses the ease of a material with which it can formed into different shapes and sizes and is closely associated with uniformity or consistency.

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